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Beluga whales (*Delphinapterus leucas*), environmental change and marine protected areas in the Western Canadian Arctic

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ABSTRACT

Two Arctic Marine Protected Areas (MPAs) (Tarium Niryutait and Anguniaqvia niqiqyuam) have been established in the Western Canadian Arctic, including the first in the Arctic, with conservation objectives directed to protect and maintain healthy beluga (*Delphinapterus leucas*) populations. The MPAs support the continued access of Inuvialuit (Western Arctic Inuit) to harvest beluga whales for food security and cultural purposes. The land claim and co-management framework for the Inuvialuit Settlement Region support the long term monitoring and management plans for this beluga population. We draw upon over 40 years of monitoring of the Eastern Beaufort Sea (EBS) beluga whale population and consider the utility of biological indicators for MPA management. In particular we focus on the conservation of a beluga population whose home range extends far beyond MPA boundaries (transboundary population with summer core area in excess of 36, 000 Km^2). We conclude that the EBS beluga whales are effective indicators of environmental change, but that we have limited understanding of the temporal and spatial relationships between beluga responses to processes that drive environmental change. Management bodies are challenged with implementing indicators that measure the impacts of 'non-manageable' stressors such as climate change, and by uncertainty in the mechanistic relationships that drive biological indicators. Given that Inuvialuit continue to be astute observers of the environment and changing conditions, our assessment suggests that Indigenous knowledge will continue to enhance the development and interpretation of beluga whale indicators for use in MPA monitoring and management.

1. Introduction

Marine protected areas (MPAs) are valuable area-based management tools used to conserve and manage marine resources. In Arctic regions, anthropogenic stressors have historically been limited relative to southern, populated latitudes; however, the Arctic is warming at rates faster with unprecedented rates of summer sea ice retreat and anomalously high sea surface temperatures between 1982 and 2012 (Stroeve et al., 2013). As a result, key physical habitat features that many Arctic marine species rely on for growth and survival are changing. Such changes include, but are not limited to, increases in the length of the ice-free season, loss of multi-year ice, and warmer ocean temperatures (Comiso and Hall, 2014; Steele et al., 2008; Stroeve et al., 2012). These changes will increase accessibility to the Arctic and human activities such as shipping and resource exploration are expected to increase (AMSA, 2009; Moore et al., 2012; Reeves et al., 2014).

In the Inuvialuit Settlement Region (ISR) of the Western Canadian Arctic, two MPAs have been established by Fisheries and Oceans Canada (DFO) under Canada's *Oceans Act* (1997). The Tarium Niryutait (TN MPA), Canada's first Arctic MPA was designated in 2010 (Gazette, 2010), and more recently the Anguniaqvia niqiqyuam MPA (AN MPA) formally designated in 2016. While the intent of the two MPAs differ, they share a common conservation priority to protect the Eastern Beaufort Sea (EBS) beluga whale (*Delphinapterus leucas*) population. This linkage between the two MPAs provides connectivity between protected areas, and recognizes the highly migratory nature of these whales, as well as their diverse preferred habitat use during the short arctic summer months (Loseto et al., 2006; Richard et al., 2001). As conservation measures for

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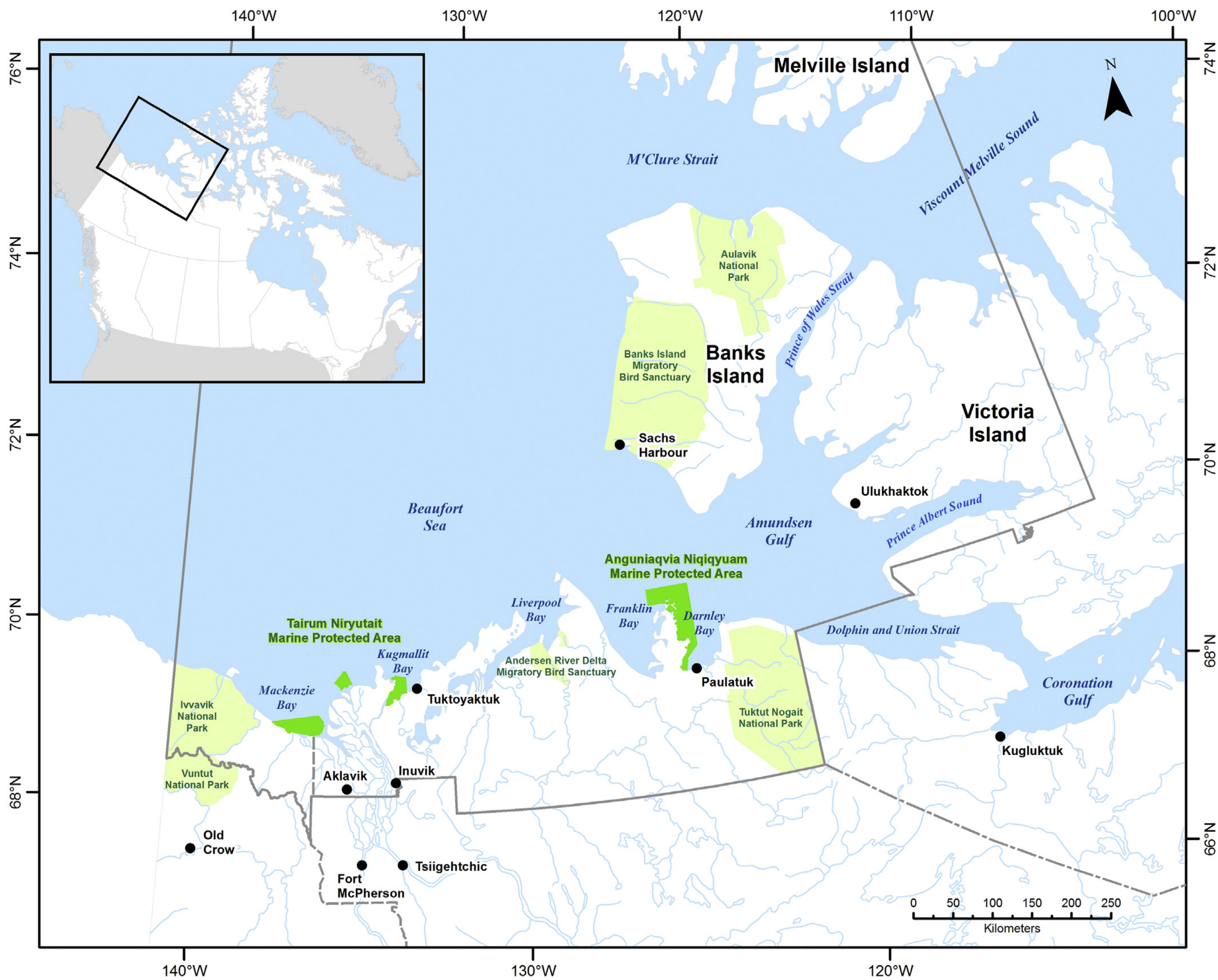

Fig. 1. Map of the Canadian Western Arctic and six communities of the Inuvialuit Settlement Region (ISR). Note the Tarium Niryutait Marine Protected Area (TN MPA) located in the Mackenzie Estuary is made up of three separate parcels, while the Anguniaqvia Niqiqyuam Marine Protected Area (AN MPA) is located in Darnley Bay near the community of Paulatuk.

the EBS beluga, the MPAs also support a cultural way of life for Inuvialuit, Western Arctic Inuit, who maintain an annual subsistence beluga hunt within the ISR (FJMC, 2013; McGhee, 1988).

The importance for conservation of the EBS beluga population was first formally recognized in the Beaufort Sea Beluga Management Plan (BSBMP) under a co-management framework (FJMC, 1991; FJMC, 1998; FJMC, 2001; FJMC, 2013). The BSBMP is closely linked to the creation of the MPAs, whereby the designation of the TN MPA was founded on the beluga management Zone 1a, which was defined as an important summering habitat for EBS beluga and traditional subsistence hunting area for Inuvialuit. Of note, both the TN MPA and BSBMP are conservation management tools that are limited to managing within their defined boundaries. (Fig. 1). Under the Inuvialuit Final Agreement (IFA), a Western Arctic land settlement agreement between Inuvialuit and the government of Canada (IFA, 1984), the Fisheries Joint Management Committee (FJMC) works in cooperation with local Hunters and Trappers Committees (HTCs) and Fisheries and Oceans Canada (DFO) to conduct beluga research and monitoring programs to support management decision making (FJMC, 2013). As a result, nearly 40 years of EBS beluga harvest monitoring data have been collected along with data for relative distribution and abundance, representing one of the strongest Arctic beluga datasets (Table 1).

The establishment of MPAs within Canada includes the implementation of monitoring and management plans that require the use of indicators as measures of effectiveness and performance. Numerous indicators and metrics (e.g. beluga diet, age/sex structure and contaminant levels, key fish abundance, biodiversity indices, ice break up dates and others) have been formally implemented for monitoring in the TN MPA (DFO, 2010). Similarly, as a key part of the implementation process, indicators will be formally adopted in support of a monitoring plan for the AN MPA. Indicators are used to reduce complexities associated with environmental data by simplifying information in a way that is useful for management and decision-making (DFO, 2013; Rice and Rochet, 2005). Indicators can also be used to describe impacts or responses to a multitude of activities and/or stressors (Doren et al., 2009). An effective indicator must be sensitive and respond to a driver, be easily detected (i.e., high signal to noise ratio) and be reflective of processes/changes in the area within a relevant timeframe (DFO, 2015). For MPAs, indicators can serve to inform on the status of the conservation objective and/or provide environmental context to help understand why a change may have occurred. EBS beluga are a transboundary population, and their migratory route spans the summering

Table 1
Long term datasets of observations and measurements of environmental variables and beluga indicators.

Indicator	TimeSpan	Finding	Reference
Environmental Variables			
Storminess	1958–2000	seasonal variation in storms, with July being the lowest month	Atkinson, 2005
Timing of ice breakup	1974–2017	ice breakup is earlier	Whalen et al., 2006–2017, this manuscript
Change in Open Water extent	1970–2000	Increased upwards of 11 days/decade	Overeem et al., 2011, Markus et al., 2009
Biological Indicators			
Arrival, Relative Abundance and Distribution	1973–1985	follow a consitent spatial and temperal pattern	Slaney, F.F. & Company Limited, 1974, 1975, 1976, 1977; Fraker, 1977, 1978; Fraker and Fraker 1979, 1981, 1982, 1983; Robertson and Millar
	1992	follow a consitent spatial and temperal pattern	Harwood and Norton, 1996
	1980–2000	Increase in beluga #'s outside of MPA	Harwood and Kingsley, 2013
	2011–2013	beluga followed ice edge	Hornby et al., 2014, Hornby et al., 2016
	2013	observation of early arrival	Hornby et al., 2016
	2015–2017	observation of early arrival	Whalen pers com
Harvest dates and locations	1987–2017	extension of harvest season	Harwood et al., 2015a
	1990–1999	additional harvested locations and numbers	Harwood et al., 2002
	2014	unusual harvest at Uluhaktuk	FJMC database, Loseto et al., 2018
Beluga diet and health metrics	1981–2012	Mercury trends suggest shift in diet exposure and ecosystem	Loseto et al., 2015b
	1989–2008	Decline in beluga size at age, suggesting diet shifts	Harwood et al., 2014b
	2012–2014	low body condition related to extensive open water, and diet biomarkers support opportunistic feeding during low condition	Choy et al., 2017

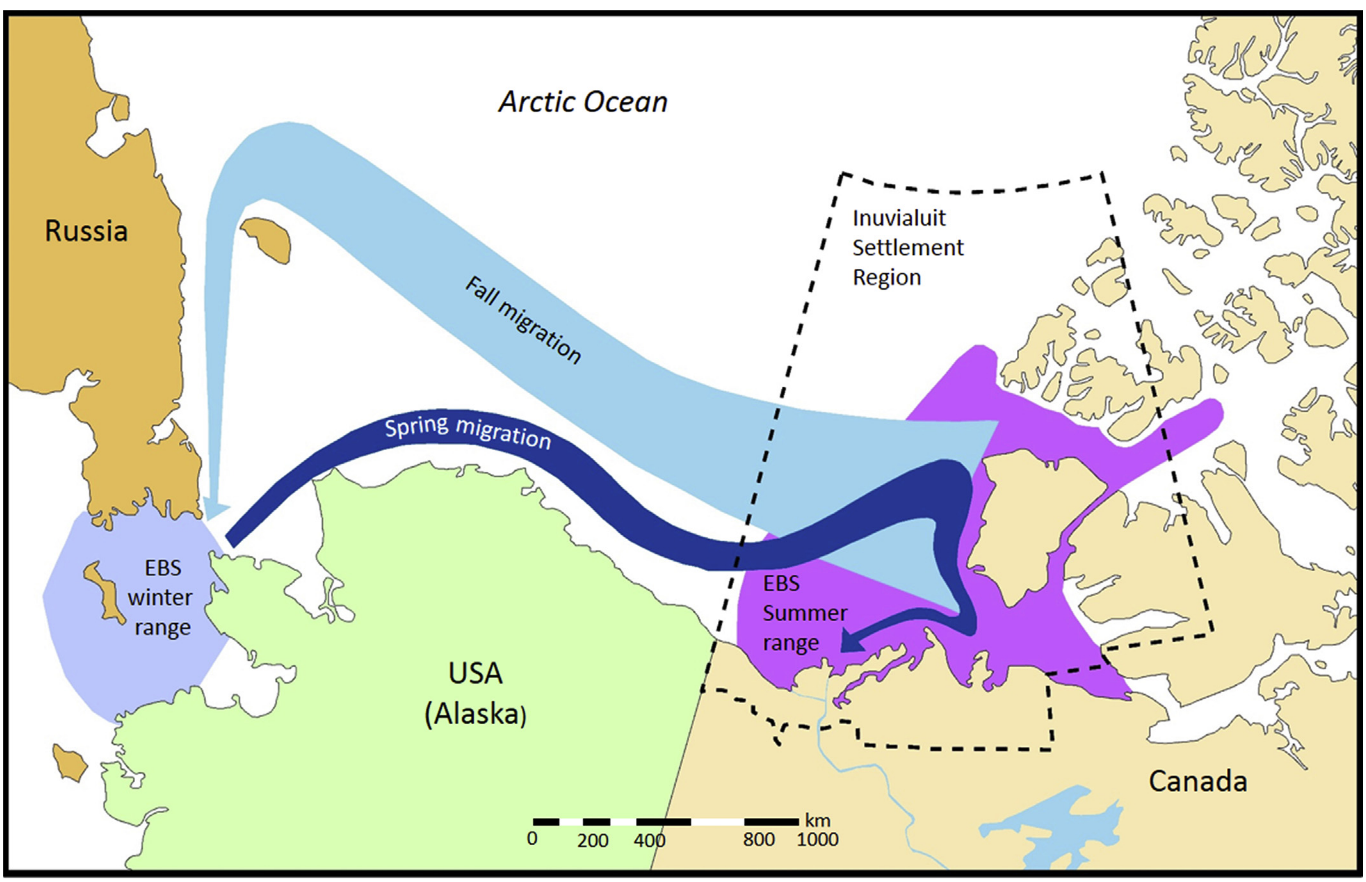

Fig. 2. The home range of the Eastern Beaufort Sea beluga population. Note the summer high use areas within the Mackenzie Estuary and the TN MPA. Figure modified from Loseto et al. (2015).

grounds within the Canadian portion of the Eastern Beaufort Sea to their wintering grounds, in the Bering Sea near Russia (Citta et al., 2017). The large home range of this population (summer core area in exceeds 36, 000 km^2 (Hauser et al., 2014) is a challenge to MPA management, not only for area-based conservation management of a species that crosses management jurisdictions, but also for the identification of indicators and the interpretation of signals from complex indicators that may reflect multiple drivers from both distant or local processes (Fig. 2). As such, careful consideration is needed for the selection of indicators, including how they may be reflecting processes occurring within or beyond MPA boundaries, as well as implications for interpretation and follow-up management actions.

These data present a unique opportunity to identify if and how ecosystem shifts may be detected in beluga indicators, and by what

means can long term monitoring of key variables support best practices in MPA indicator selection and management decision-making. Here we focus on the TN MPA, review long-term data pertaining to the conservation objective, and assess whether long-term biological data for beluga population and condition are appropriate indicators for MPA monitoring and management. Specifically, we examine trends in relative distribution and abundance, timing of arrival, harvest parameters, and diet and health indicators of EBS beluga in context with potential environmental drivers and trends. Criteria are used to assess the effectiveness of these long-term datasets in a technical and management application for MPA indicators, as well as to support recommendations for future monitoring approaches. We conclude with a discussion of the societal implications associated with the success of MPAs, and the livelihoods of the Inuvialuit who depend on them for subsistence.

2. Methods

2.1. Study area and beluga habitat use

The TN MPA is located in the Mackenzie River Estuary, and the AN MPA is located in Darnley Bay and Amundsen Gulf, both in the Beaufort Sea, within the marine portion of the ISR, Northwest Territories Canada (Fig. 1). Telemetry data from the 1990s indicated that belugas spent on average 3–5 days in the estuary following tagging (Richard et al., 2001). While residing in the estuary, the distribution of belugas is highly clumped (Norton and Harwood, 1986; Harwoodet al., 2014c), but they also occur throughout the offshore Beaufort Shelf concurrently during July (Norton and Harwood, 1985). In contrast to the clumped distribution during the summer aggregation in the Mackenzie Estuary, beluga distribution across the Beaufort Sea and Darnley Bay is typically widespread, and consists almost exclusively of single individuals or small groups of 2 or 3 whales (Norton and Harwood, 1985; Harwood et al., 1996, Harwood and Kingsley, 2013). Telemetry data indicate that after leaving the estuary, EBS belugas travel offshore to areas several 100 Km beyond the Beaufort Sea shelf, including eastward to Amundsen Gulf (mostly younger males, females) and Viscount Melville Sound (larger males) as well as the AN MPA in the Amundsen Gulf/Darnley Bay area (Richard et al., 2001).

2.2. Physical habitat

The Beaufort Sea is ice free for approximately 4 months from June–September, during which time the region receives significant fresh water and sediment input from the Mackenzie River Delta, as well as several smaller rivers. This area remains fresh throughout the year but can be influenced by storm conditions that bring cold ocean water into the delta. Deltaic sedimentation predominantly controls the seabed morphology extending the shallow (< 5 m) contour over 50 Km from the delta front. However localized coastal erosion (average rates 1.1 m/yr and up to 20 m/yr) has been observed to influence sediment distribution in the nearshore as well (Solomon et al., 2005). The areas within the TN MPA are generally between 2 and 3 m water depth and primarily consist of very fine deltaic seabed sediments (silt) with some pockets of coarse (sand) material along the shore and distributary mouth bars (Lintern et al., 2005; Loseto et al., 2015). In comparison, the AN MPA located in Darnley Bay has very little deltaic influence from the Hornaday and Brock Rivers, and contains deeper oceanic waters (water depths exceeding 100 m). Coastal erosion is very low along the primarily bedrock coastline, with seabed geology consists of coastal and marine clays (Paulic et al., 2011). The AN MPA has a very diverse benthic ecology relative to the TN MPA largely because the deep bathymetry avoids the influence of ice movements and wave action, unlike the TN MPA where both ice and waves disturb the benthic habitats.

2.3. Data collection

Here we review findings and observations from previously published studies on EBS belugas that assess data spanning more than 40 year time span. We review data collected on EBS beluga using harvest-based monitoring and aerial surveys as well as data on external environmental variables including sea ice extent, open water storminess and ice break-up timing (Table 1).

Environmental data: The assessment of long term Pan-Arctic climate data to more localized storminess within the MPA can be used to assess the long-term data for seasonal, annual and decadal variability of wind and subsequent ocean wave conditions. Long term data (1958–2000) containing wind conditions (Atkinson, 2005) are presented. Sea-ice extent in particular the date of landfast ice break-up (late June) provides important information about the changes in physical condition of the TN MPA and accessibility of the estuary to the open ocean. Ice keel scours and pit depressions along the seabed that form during the breakup and melting of ice have been observed in the estuary (Whalen et al., 2014). Ice break-up dates as published in (Norton and Harwood, 1986; Whalen et al., 2012, 2013, 2014, 2015, 2016, 2017)were paired with observations made from publically accessible optical satellite imagery available from the United States Geological Survey (USGS) https://lta.cr.usgs.gov/AVHRR and NASA https://worldview.earthdata.nasa.gov/.

Relative distribution, abundance and arrival times: Areas of beluga presence, distribution and relative abundance have been captured using aerial surveys across different seasons, years and locations within the EBS beluga summering habitat. Beluga presence and entry into the Mackenzie Estuary were historically monitored with spring aerial surveys (mid to late June). The spring "reconnaissance" aerial surveys that typically followed the land fast ice edge that formed across the estuary began in 1973 (Slaney, 1974), ran consecutively to 1985 (Norton and Harwood, 1986), again in 1992, and most recently from 2011 to 2013 (Hornby et al., 2014) (Table 1). During the summer (July–August) "systematic" aerial surveys were conducted in the Mackenzie Estuary to determine relative abundance and distribution of belugas (Harwood and Norton, 1996). During late summer and fall cetacean aerial surveys on the Beaufort Sea Shelf and offshore deep waters occurred in 1982–1985 and again in 2007–2009 (Harwood and Kingsley, 2013).

Harvest monitoring Data: The EBS beluga whale harvest has been monitored annually since 1973, when harvest numbers were recorded by a local hunter and an independent contractor, and biological samples were collected opportunistically when possible (Harwood et al., 2002). Beginning in 1980, up to six local hunters were hired each summer to record harvest statistics (number of whales struck, lost, and landed), to collect biological samples to determine sex record presence/absence of stomach contents, and to measure the standard length of whales (Harwood et al., 2002). Blubber thickness measurements were recorded at the sternum of harvested whales from 2000 to present (Harwood et al., 2014b). Liver samples were collected from the Mackenzie Delta in 1981, 1984, 1993–1996, 2001 for mercury analysis (Lockhart et al., 2005). As of 2001, tissue samples were collected by a community monitor and were analyzed for one or more of the following contaminants: mercury concentration, persistent organic pollutants, perfluorinated and brominated compounds, cesium-137, or stable isotopes of carbon and nitrogen and fatty acids, (Braune et al., 2005; Loseto et al., 2015; Stocki et al., 2016; Tomy et al., 2009). Age estimates were determined from a thin section of tooth by counting growth layer groups (one growth layer group deposited per year) in the dentine (Stewart et al., 2006). Blood samples were collected from 1989, 1993–1996 and 2001 to test for Brucella spp. antibodies (Nielsen et al., 2001). From 2006 to 2010, additional samples were collected for ecotoxicological studies to assess the relationship between mercury and organic contaminants on components of the nervous (Ostertag et al., 2014), hepatic (Noël et al., 2014), endocrine (Desforges et al., 2013) and immune systems (Frouin et al., 2012).

Traditional Ecological Knowledge: Inuvialuit have consistently played a leadership role in beluga monitoring programs and data collection. In recent years, the monitoring program has expanded to include Traditional and Local Knowledge (TLK) about beluga whales (Ostertag et al., 2018; Waugh et al., 2018), through the use of semi-structured interviews and harvester questionnaires. Traditional knowledge and observations made during harvesting activities strengthen the monitoring of beluga health, diet, timing and distribution. More specifically Inuvialuit provide knowledge and observations to track potential shifts in diet by recording feeding behaviour and collecting gut contents (physical samples or photographs), characterizing the health and condition of harvested whales, which complement current monitoring of beluga health and condition indicators (e.g. size and blubber thickness), and contextualize these data within their broader understanding of ecosystem processes and change.

Qualitative Indicator Analysis: The previously published trend data were assessed for use and application as MPA indicators using criteria proposed by Rice and Rochet (2005). We selected four criteria for discussion of indicator assessment; we selected two of the three 'high' ranked criterion under the technical and managers/decision-makers criterion. Technical criteria selected are Theoretical Basis, which relates to the data and knowledge available to build confidence in theory, and Sensitivity, which reflects the need for an indicator to respond to a system or stressor. The manager criteria selected are Responsiveness, which reflects the effectiveness of management plans, and Specificity, which reflects the ability to take actions to remedy problem or manage activity (Rice and Rochet, 2005). The remaining 'high' ranked criteria not being assessed here include 'Historical Data', this was not assessed because it was considered 'high' for all beluga datasets evaluated here given the longevity of these datasets, the second criterion not assessed was 'Cost' given the scope of this paper. The assessment is qualitative and is used as a means to discuss the application of the datasets as indicators for MPAs. The data were qualitatively ranked as high, medium or low for each criterion.

3. Results

3.1. Changes in the long-term environmental dataset

The Beaufort Sea region has experienced some of the fastest rates of sea ice cover change in the entire Arctic (Shirasawa et al., 2009). Within the TN MPA, there has been a notable shift in the date of landfast ice break-up, which now occurs an average 10 days earlier, and in extreme years up to 20 days earlier relative to break-up dates in 1974 (Fig. 3). The earliest dates for break-up of the landfast ice bridge in Kugmallit Bay was June 13, 2016 and June 15, 2015 (Whalen et al., 2015, 2016). The latest date of break-up that occurred in the region was on July 10thin both 1974 and 1982.

The changing landfast ice conditions in the MPA have created more open water allowing for ocean surface waves to develop during periods of increased winds which have the potential to generate significant coastal storms. Previous work by Atkinson (2005) suggested that wind speeds greater than 10 m/s are significant enough to be classified as coastal storms. Coastal storms can lead to increased wave height and frequency which can lead to coastal erosion (Overeem et al., 2011). Open water duration has increased as fast as 11 days per decade (Markus et al., 2009). Data at the pan-Arctic scale indicate that between 1958 and 2000, wind speed, on average increased, and increased storms through the open water season (June–Oct) (Atkinson, 2005).

3.2. Changes in beluga timing of arrival, relative abundance and distribution

The arrival of beluga to the Mackenzie Estuary and TN MPA along with relative distribution and abundance within the Estuary were monitored consistently using aerial surveys during the height of oil and gas activity in the Beaufort Sea during the 1970–1980s (Harwood et al., 1996; Norton and Harwood, 1986) (Table 1). More recently (i.e., 2012, 2013), aerial surveys documented the arrival of beluga whales to the Mackenzie Estuary were consistent with observations made in historical surveys (1974–1984), whereby beluga travel along the seaward side of the land fast ice bridge waiting for ice break up before entering the estuary (Hoover et al., 2016a; Hornby et al., 2014). While the beluga have a tendency to follow the sea ice edge *en route* to the estuary, as observed over a 40 year time frame, the timing of arrival has shifted in relation to sea ice changes. Whales were spotted in the estuary by a research crew shortly following the unprecedented early ice break-on June 13, 2015 and June 15, 2016 (Whalen and Gordon, pers. comm) highlighting the link between beluga arrival and movement into the estuary following ice break up.

Outside of the boundaries of the TN MPA systematic aerial surveys determining the relative abundance and distributions during the late summer revealed that the number of beluga were three times higher in the 2000s relative to the 1980s (Harwood and Kingsley, 2013). These

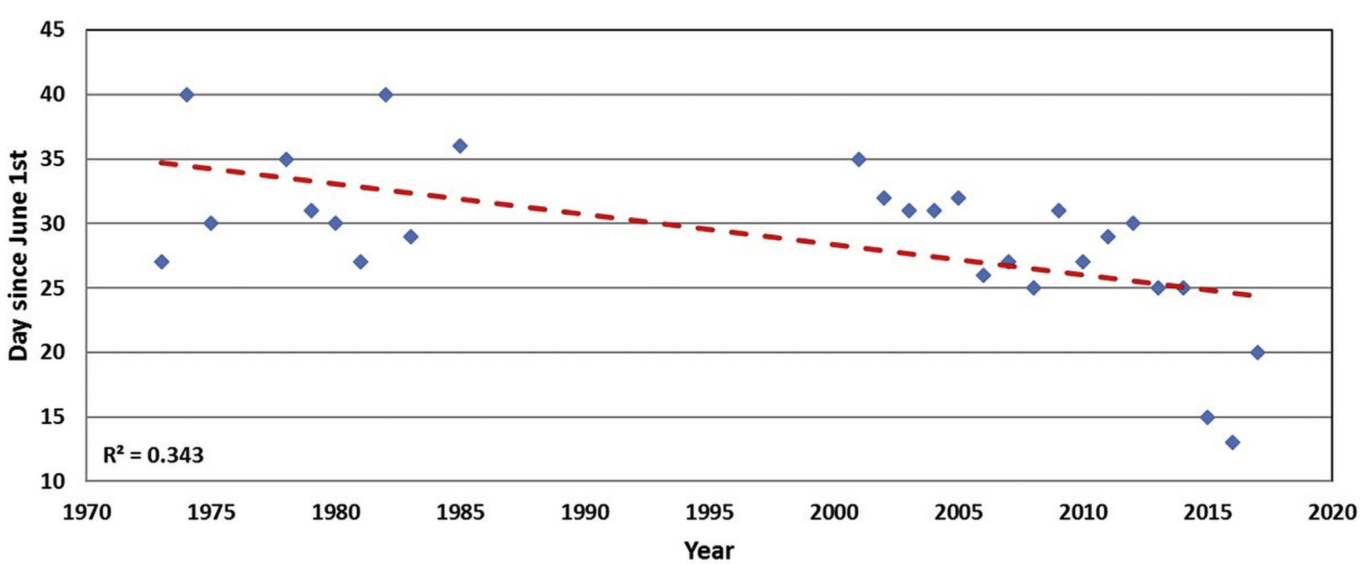

Fig. 3. Data from 1973 to 1985 and 2001–2017 show the timing of landfast ice breakup in the TN MPA, Kugmallit Bay. Trend line (in red) shows earlier breakup by also 10 days over the 45 year period. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

surveys occurred along the Beaufort Sea shelf and offshore from the Alaskan boarder to just east of Cape Bathurst. The relative distribution of observed belugas did not change within the Beaufort Sea study area from both time series along the continental shelf north of the Tuktoyaktuk Peninsula and 30 km seaward of the Mackenzie Estuary area (Harwood and Kingsley, 2013). While distribution remained consistent the increase in relative abundance by three fold could not accounted for by population growth alone (Harwood and Kingsley, 2013).

3.3. Shifts in beluga harvest dates and locations

Trend analyses over the past 30 years (up to 2009) reveal an extended harvest season in parts of the TN MPA and AN MPA that suggest changes in the arrival and exit dates of beluga to these regions (Harwood et al., 2015a). When beluga monitoring began prior to the 1970s, the majority of belugas were harvested in the Mackenzie Delta, within what are now the boundaries of the TN MPA. Beginning in 1989, Inuvialuit in Paulatuk, located in Darnley Bay (now associated with the AN MPA) began to regularly harvest beluga whales (Harwood et al., 2002; McGhee, 1988). Previously, availability of beluga was limited in the AN MPA, but from 1990 to 1999 the community of Paulatuk landed 91 whales (mean of 9 whales per year) (Harwood et al., 2002). In recent years (2010–2015) the community landed 106 whales, averaging just over 17 whales per year (FJMC, 2013). Also during this time, there has been a decline in beluga harvested in the Shingle Point/Shallow Bay area of the TN MPA (Aklavik harvesters (FJMC, 2013);).

Similar to harvests in the AN MPA, there have been sporadic harvests of beluga outside the TN MPA in the two outlying marine coastal communities of Sachs Harbour and Ulukhaktok (Collings et al., 2018). For example, historical records for the community of Ulukhaktok showed one whale landed in 1973, seven in 1975 and two in 1978 (Strong, 1989), with recent records of three landed in 2004 and one in 2005 (FJMC database). In 2014, beluga whales were spotted in significant numbers near Sachs Harbour and Ulukhaktok throughout the summer (July to August). That year, over 30 whales were harvested in Ulukhaktok, an unprecedented number of whales for the community (FJMC, 2013). These numbers were higher than those harvested from Tuktoyaktuk in the TN MPA, where 18 beluga were landed that same summer, in contrast to previous years where approximately 40 per year are landed (Harwood et al., 2002). While there has not been another repeat of the 2014 harvest in Ulukhaktok, the community of Sachs harbour has continued to harvest up to 3 whales per year since 2010 (excluding 2011, FJMC database).

3.4. Shifts in beluga diet and health related indicators

Traditional and Local Knowledge interviews and questionnaires indicated that condition of harvested whales has declined in some recent years (Waugh et al., 2018). The long-term harvest monitoring of beluga revealed a slight, yet sustained decline in beluga size-at-age of nearly 1% per year from 1989 to 2008 (Harwood et al., 2014b). These findings along with a high year to year variation in blubber thickness were hypothesized to reflect ecosystem changes and potentially a decline in high quality prey (Harwood et al., 2014b). Over a similar time frame (c.a. 1981 to 2012), trends in the concentration of mercury, a biomagnifying contaminant, in harvested beluga suggested shifts in dietary exposure (Loseto et al., 2015). After removing the effect of size and age, a non-linear trend was revealed whereby mercury concentrations peaked in the late 1990s early 2000s (Loseto et al., 2015). This trend did not follow the linear increase in atmospheric mercury emissions, nor was it easily explained by diet (as defined by stable isotopes). Evaluation of climate variability variables (e.g. Arctic oscillation (AO), Sea-ice minimum (SIM) and the Pacific Decadal Oscillation (PDO)) revealed a significant correlation between mercury levels with the PDO on an 8 year time lag. The authors suggest that the lag time reflects the time for system changes to propagate up the foodweb and be observed in a high trophic level species like beluga whales. As such, mercury trends in beluga may reflect distant drivers of climate variability that likely altered foodweb characteristics and the dietary exposure of mercury (Loseto et al., 2015).

Despite access to numerous beluga stomachs from the subsistence harvests, determining beluga diet has been difficult as the stomachs are often empty or only contain undigested prey hard-parts (i.e. fish otoliths, squid beaks). Analyses of hard parts in gut contents together with dietary biomarkers (e.g. fatty acids) have indicated Arctic Cod (*Boreogadus saida*) as a key prey species for belugas (Loseto et al., 2009; Quakenbush et al., 2015). It is important to note that beluga are generalist feeders and Quakenbush (et al., 2015) observed up eight fish species and 16 invertebrate in spring harvested EBS stomachs. Recent evaluation of beluga condition and fatty acids (2011–2014) revealed that the lowest body condition (maximum girth, blubber thickness) of harvested whales on record occurred in 2012 and 2014, which were years with greater open water (Choy et al., 2017; Hornby et al., 2016). These observations were consistent with harvesters' observations that beluga condition was poorer in 2014 than 2015 (Ostertag et al., 2018). Belugas harvested in 2012 and 2014 also had the largest isotopic niche space supporting more generalist feeding strategy. Fatty acid profiles of the 2014 belugas revealed low levels of copepod markers, suggesting a reduced consumption of Arctic Cod who predominately feed on copepods (Choy et al., 2017). Stomachs of beluga from the unusual 2014 harvests in Ulukhaktok did contain partially digested prey. Interestingly, stomach contents were not dominated by Arctic Cod, but rather by Sandlance (*Ammodytes* spp.), a small burrowing fish (Loseto et al., 2018).

4. Discussion

4.1. Beluga distribution and movement in response to environmental variables

Access of belugas to their core summer aggregation within the TN MPA is limited by the landfast ice bridge that forms offshore of the estuary in springtime. Subsequently, there is a direct link between ice break-up date and beluga timing-of-arrival into the estuary, with a shift toward early dates observed over the past 45 years. Due to this linkage, beluga timing-of-arrival ranked high for the technical indicator criteria *theoretical basis* and *sensitivity* (Table 2). Under the manage criteria *responsiveness* it ranked low because management capacity is limited in ability to alter drivers of arrival time (i.e. ice break-up date). However, the indicator ranked high to *specificity* because it supports the ability for management to take actions on activities occurring within the MPA (Table 2). Despite some high rankings for this indicator, beluga timing-of-arrival may be better monitored using more readily available proxy

Table 2
Assessment of long term data against indicator criteria selected from Rice and Rochet, 2005. Technical and Management criterion are ranked high to low in a qualitative fashion.

Indicators	Screening Criterion for Candidate Indicators			
	Technical		Management	
	Theoretical basis	Sensitivity	Responsiveness	Specificity
Arrival	high	high	low	high
Relative Abundance and Distribution*	low	high	low	low
Harvest dates and locations	medium	high	low	high
Beluga diet and health metrics	medium	high	low	medium

* Measured outside the boundaries of the TN MPA.

data for land-fast ice conditions. Implications of beluga early entry into the TN MPA and how this biological response at a local level may manifest into distribution patterns at larger spatial scales remains unknown, and should be a focus of future studies. The apparent increase in beluga relative abundance estimates in the Beaufort Sea between the 1980's relative to the 2000's raises questions about possible drivers and highlights the importance of conducting periodic population assessments for trends in distribution, relative abundance and habitat use both within and beyond the MPA boundaries. Population increases alone could not explain the change in abundance, and it may be that the offshore area became more attractive to beluga in the 2000s due to a decline in industrial activity and/or, shifts in prey availability (Harwood and Kingsley, 2013). While difficult to definitively identify the direct driver of increased beluga occurrence in the offshore, findings from several studies demonstrate that beluga are sensitive and responsive to changes in acoustic habitat. For instance, belugas have been observed to avoid ice-breaking ships at distances of 35–50 Km, and to send alarm vocalizations triggered by a ship as far away was 80 km (Cosens and Dueck, 1993; Finley et al., 1990). Due to a lack of understanding of the environmental drivers of these trend data, relative abundance ranked low for the *theoretical basis* criterion but was ranked high in *sensitivity* given our understanding in beluga displacement and movement. Management criterion ranked low for *responsiveness* because this indicator is outside of the MPA and management actions would not reflect effective MPA management. It also ranked low for *specificity* because it remains unclear what management actions or strategy would remedy declines in abundance or shifts in distribution outside the MPA. Understanding beluga displacement and movement in context with prey availability would require simultaneous data on the movement of both beluga and potential prey. Such data are currently unavailable.

4.2. Beluga harvest dates and locations within and outside of MPAs reflect ecosystem change

The Inuvialuit from Inuvik, Aklavik and Tuktoyaktuk hunt beluga that form large aggregations in July (Harwood et al., 2002). The longer harvest season may reflect several recent changes. Earlier arrival of belugas into the estuary/TN MPA is associated with earlier harvest dates at some locations; however, harvest dates extending later into the season may reflect accessibility challenges, due to adverse weather conditions (i.e. increased winds and storms), whereby hunters are willing to extend their time hunting to secure a beluga (Wesche and Chan, 2010). In recent years, storm activity has increased during the core harvest period (July), it has become apparent that not only posing safety and accessibility challenges, but also exposing many subsistence camps within the TN MPA to increased periods of storm surge flooding and erosion.

Outside of the TN MPA boundaries, changes in beluga occurrence over space and time and associated accessibility to humans have direct consequences on harvest practices. In some cases, such as for the communities of Ulukhaktok and Paulatuk, changes in beluga travel routes led to increased accessibility of whales and consistent or sporadic increases in harvest numbers. In other communities, such as Aklavik, factors may have led to reduced harvest numbers are unclear. It remains unknown what predominant factors increased accessibility to beluga for harvest near Paulatuk. TLK about the area indicated that in the past, beluga whales did not travel along the western coast of Darnley Bay (T. Green, personal communication, August 6, 2015). Consideration of harvest demographics as an MPA indicator ranked medium for *theoretical basis* because the harvest data reflects social, cultural and economic drivers (Hoover et al., 2016d) as well as to beluga and environmental parameters making interpretation of trends in these data complex and requiring the collection of numerous supporting variables for proper interpretation (Table 2). Harvest demographics ranked high for *sensitivity* due to reasons listed above, whereby harvest demographics are sensitive to numerous parameters including environmental and non-environmental drivers. The management criterion r*esponsiveness* was ranked low because management actions cannot alter beluga movement patterns or their accessibility to communities. However, this indicator ranked high for *specificity* because management can act on activities that may interfere with harvest activities, as well as act on harvest regulations and guidelines.

The unusual predominance of Sandlance in stomachs of harvested beluga near Ulukhaktok, combined with the low abundance of adult Arctic Cod in the Beaufort Sea in 2014 (Geoffroy, 2016), suggests that beluga may have shifted their distribution in response to availability of key prey items (Loseto et al., 2018). Beluga harvested in the TN MPA in 2014 had poorer body condition, lower copepod fatty acid signatures, and biomarker signals indicating a of a generalist feeding strategy (large isotopic niches) that associated with a low sea ice year (Choy et al., 2017). While further investigation is required to substantiate the relationship of the high occurrence of belugas near Ulukhaktok in summer 2014, a shifting preferred prey base would support the change in beluga movement patterns, and the linkage between distribution and condition of beluga harvested both within and beyond the boundaries of the TN MPA.

4.3. Beluga diet and health measured within MPAs indicate regional scale ecosystem shifts

Changes in beluga physiology, diet and mercury concentrations may be best explained by ecosystem shifts occurring at the regional scale, despite measurements taken from whales harvested within the TN MPA. The decline in beluga size at age may be a result of ecosystem shifts that have altered the beluga prey base, either by reducing prey availability or quality (Harwood et al., 2014a). Similar findings and trends in declining body condition metrics have been identified in two other marine species in the Beaufort Sea, the ringed seal and black guillemot chicks (Harwood et al., 2015b). Declines in the abundance of Arctic Cod, suspected as a factor for ringed seal declines (Harwood et al., 2012, 2015b) and are directly linked to the declines in black guillemots (Divoky et al., 2015) suggesting parallel lines of evidence in multiple predators. In addition, mercury trends in beluga samples were best related to lag-time relationships with the regional scale climate drivers, notably the Pacific Decadal Oscillation (PDO), which suggests that regional scale drivers may be influencing ecosystem processes such as the energy transfer up food webs and the structure of foodweb guilds (Loseto et al., 2015). That is, the cascading impacts of climate change, has affected primary production (e.g. timing, species composition) (Arrigo and van Dijken, 2004) that can propagate energetic impacts up the foodweb and affect the quality (i.e. energy content), the quantity and the availability (over space and time) of prey for higher trophic level species (Litzow and Mueter, 2014; Moore, 2008) that can influence biomagnification processes of mercury to beluga whales (Loseto et al., 2015).

The interpretation of beluga trends and linkages to prey and ecosystem shifts is challenged by the lack of supporting data to confirm the specific linkages between environmental variables, the foodweb and how shifts in the two are manifested in beluga. Arctic cod is an important forage species for many arctic marine predators (Bradstreet et al., 1986; Hoover et al., 2013; Welch et al., 1992); however, there are no ongoing monitoring programs for Arctic cod in the Beaufort Sea. Until science develops a more comprehensive understanding how changes in the environment and lower trophic levels are propagated though the food web, our understanding of ecosystem processes is reliant on sentinel species such as black guillemots and belugas, whereby changes in diet and/or condition suggest changes in prey base (quality and quantity) in the supporting ecosystem. As such, together these data on beluga diet and health metrics ranked medium on *theoretical basis*. These data did demonstrate *sensitivity* to ecosystem changes and thus ranked high for this indicator criterion (Table 2). Within the boundaries of the TN MPA management is unable to respond to drivers that are

operating at a regional or global scale, thus ranking low for *responsiveness*. Specificity was ranked medium because there is ability to consider the regional and global drivers and/or stressors when managing activities within an MPA by using a cumulative framework approach that limits activities or stressors within and MPA by considering external pressures. While beluga health and diet metrics may offer an opportunity to observe ecosystem change, to effectively use them for MPA indicators there is need to collect parallel datasets for ecosystem components to define the limits of interpretation and causation.

4.4. Management: responding to indicator datasets

Despite beluga indicators showing high sensitivity, many example data sets lacked the specificity of how beluga metrics responded to drivers, which challenges the use these indicators for management to be responsive and demonstrate effectiveness in management plans or actions. These disconnects between highly sensitive data and management actions may be strengthened with the use of thresholds or reference limits, that have not been developed for these data sets (e.g. size-at-age or timing of beluga to traditional hunting areas) and could provide better coupling between the technical advice of an indicator to the management action. Of greatest challenge for MPA management actions are those instances where knowledge is lacking on specific 'relationships' between beluga indicators and drivers of change. In the absence of these specificities, these datasets are still of great value because the indicator data acts as a warning signal for marine resource managers to proceed with caution (i.e. precautionary approach) and strengthen research and monitoring programs to gain a better understanding of ecosystem processes and better inform management.

The existing beluga management plans (i.e. BSBMP, TN MPA) and regulatory agencies (e.g. Transport Canada, Fisheries and Oceans Canada) only regulate human activities, as opposed to shifts in ecosystem processes (e.g. reduced availability of Arctic Cod). This raises the question can management use indicators that reflect outside or unmanageable system processes (e.g. ecosystem shifts, or international scale decision-making) and should investment be made towards these data collections? While MPA management jurisdictions may be limited the data can be put forward to other national or international conventions (e.g. Stockholm Convention). Decisions around human activities (e.g. resource development, shipping) that offer important socio-economic opportunity require a balanced approach based on accurate understandings of the ecosystem responses to specific human activities. Under such scenarios managers are forced to consider a cumulative impacts approach to managing human activities that includes findings from indicators that can point to an ecosystem shift or population close to their tipping point. While there is confidence around the management and mitigation of direct impacts of human activities, there remains a need to build a cumulative picture of all stressors and the current state of beluga and their supporting ecosystem. To effectively do this baseline data collected over a long-term is needed, along with corresponding measurements to support knowledge of beluga responsiveness, and lastly a measure of confidence around these data to support decision-making.

Despite the substantial data for the targeted beluga indicator species and a demonstration of their sensitivity to ecosystem changes, we lack detailed mechanistic understandings to provide specific guidance for MPA management actions. Developing research programs to address these linkages and strengthen the utility of indicators in necessary. Additionally, unlike managing the direct effects of a human activity on a species or ecosystem, managing those direct effects in context with an understanding of cumulative stressors, in particular climate change driven shifts will require further research. In the interim we recommend continuing the TN MPA and developing the AN MPA management strategy that employs a precautionary approach to managing human activities while developing a cumulative impacts management framework that includes non-manageable stressors such as climate driven ecosystem shifts.

4.5. MPA success and implications for Inuvialuit

Hunting beluga has, and continues to be, of economic, dietary, and cultural importance for Inuvialuit (Geraci and Smith, 1979; Hidiroglou et al., 2008; Usher, 2002). Beluga muktuuq (skin with thin layer of blubber) is nutritionally superior to and preferred over many of the store bought food items, which are often expensive to purchase (Hoover et al., 2016a; Kinloch et al., 1992; Rosol et al., 2016), and participation in the beluga subsistence hunt is an opportunity to pass on hunting knowledge and land-based skills to younger generations, including the cultural values associated with sharing of country foods (locally harvested fish and wildlife) with family and the wider community (Hoover et al., 2016d; Huntington et al., 1999; Pearce et al., 2011). Changes in beluga distribution and condition could influence availability, quality and quantity of this food resource for the Inuvialuit hunters who depend on them for subsistence.

Changes in beluga distribution, relative abundance, arrival to summering locations, diet and health appear to be responding to habitat changes and a shifting prey base resulting from climate change drivers. This means that for some Inuvialuit, beluga are shifting arrival and departure times at key hunting locations (e.g. Kugmallit Bay), whereas for others, beluga are sporadically emerging as a more common species important for subsistence (e.g Ulukhaktuk, Sachs Harbour). Potential increases to contaminant exposure or decline in overall health may decrease the high quality of this food resource. Now, with documented changes in beluga diet, distribution, arrival time to key harvest locations, along with the recent harvest of 30 + whales in Ulukhaktok, this heightens the needs to monitor key indicators as well as understand how they can support decision-making.'

While research and monitoring studies have identified shifts in beluga metrics such as relative abundance and size-at-age, the underlying ecosystem processes and mechanisms that drive such shifts remains poorly known. Even with 40 + years of beluga harvest monitoring and distribution studies, western science has provided a 'short-term' view of the ecosystem when compared with 'Indigenous knowledge.' Indigenous knowledge of beluga and the surrounding natural environment is a cumulative knowledge that spans generations and accounts for variations in the environment that are not captured by monitoring and distribution studies, either because of study design or the timing of deployment. Understanding how Inuit and Inuvialuit view our relationship with the natural environment and how it is changing is the starting point from which to incorporate Indigenous knowledge into long-term environmental monitoring. From there, different aspects of the Indigenous knowledge system can be activated to help guide monitoring and enhance understanding of beluga and environmental change (Usher, 2000). Continuing to engage local people is critical to ensuring that Inuvialuit knowledge about the environment for a large area and long time-span are included in management and decision-making (Usher, 2000). These observations and hypotheses complement observations made by the scientific community that are instrumented, quantified and recorded (Usher, 2000). Community-based monitoring outside of MPAs provides an important mechanism to increasing our understanding of how beluga adapt to environmental change.

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